STRUCTURAL MAPPING OF THE GORDON LAKE 'REFOLD', NWT: A MODEL FOR THE FOCUSSING OF LATE-STAGE, GOLD BEARING QUARTZ BRECCIA-VEIN SYSTEMS

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EGS 1988-4 Structural mapping of the Gordon Lake 'refold', NWT. Parts of NTS areas 85 I/15 and 85 P/3.
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ABSTRACT

Structural mapping of meta-turbidites from the Burwash Formation of the Archean Yellowknife Supergroup, in the hinge zone of the Gordon Lake 'refold', N.W.T. has identified at least three deformational events (D1, D3 and D4) and seven vein types. Of the vein types, the latest, gold mineralized quartz-breccias (Type 7) found near Knight Bay, Gordon Lake (lat. 62° 54'N and long. 113° 15'W) are the most economically important, due to their larger size and tonnage potential. The quartz-breccias were formed during the late stages of deformation (D4) and are restricted to crenulation zones in the centre of the refold along the axial trace. The crenulation zones developed preferentially in the centre of the refold due to late (D4) asymmetrical tightening and hinge migration.

Structural data is compatible with a model whereby late metamorphic fluids were focussed through a permeable zone formed by hydraulic fracturing, which accompanied the late hinge migration, towards the centre of the Gordon Lake refold. Foliation and earlier formed quartz veins (Types 1,2,3,and 5) enhanced the brecciation mechanisms. The source and the nature of the mineralizing fluids are unknown, but the age of the main mineralizing event is possibly coincident with the thermal effects of late granitic plutons. Precipitation of gold may have been triggered by decompression and cooling phenomena associated with hydraulic fracturing, and the high organic carbon content of the siltstones. Geochronology, mineralogic, isotopic and fluid inclusion studies are underway to test genetic models.

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1. INTRODUCTION

This report fulfills the requirements of a 1987-88 Mineral Development Agreement contract between the Government of the Northwest Territories and Drs. M. Zentilli and N. Culshaw, Dalhousie University, Halifax, N.S. The purpose of the contract was to study turbidite hosted, gold breccia-vein systems, of the type found near Knight Bay at Gordon Lake, (Map 1, in back pocket). The report summarizes field observations at Gordon Lake, and outlines a regionally predictive model which will assist in the exploration for additional breccia-vein deposits. Field work was carried out by T. Stokes (MSc) during the summers of 1986 and 1987, under the guidance of N.Culshaw.

The breccia-vein occurrences at Knight Bay, on the south-western end of Gordon Lake, are situated 70 km NE of Yellowknife, at latitude 62° 54' N and longitude 113° 15' W, (N.T.S. maps 85 I/15 and 85 P/3), and lie within the Burwash formation meta-turbidites of the Yellowknife Basin, the southern most geological domain of the Archean Slave Province.

The Burwash formation of the Yellowknife Supergroup, defined by Henderson (1970), constitutes the bulk and core of the basin, which is inter-fingered with, and flanked by generally older Supergroup meta-volcanic formations. These (approximately 2.7 Ga old) Yellowknife Supergroup formations possibly overlie an ancient (3.2-3.6 Ga) basement granite-gneiss (Henderson, 1985) and are intruded by multiple, relatively young (2.56-2.68 Ga) plutonic phases, (Henderson et al., 1988 and van Breemen et al., 1988). Metamorphism within the Yellowknife Basin varies from upper amphibolite to lower greenschist grade. The grade is, in part, spatially controlled by late plutonic phases and is the result of an extended thermal doming event (Thompson, 1978). Gordon Lake is located within the lower grade meta-turbidites which are intruded in the west by the late Prosperous granite, and to the east abut against the Cameron Lake meta-volcanics and the Sleepy Dragon basement complex.

For further details on Burwash Formation stratigraphy see Henderson (1975, 1987); for metamorphism, Kamineni et al. (1979) and Ramsay et al. (1977); for structure, Drury (1977) and Fyson (1975, 1980, 1981, 1982, 1984); and for previous work on gold-quartz veins, Padgham (1984, 1986), Fyson (1986) and Stokes, Zentilli and Culshaw (1987a, 1987b, 1987c, 1988a and 1988b).

2. PREVIOUS WORK AND RELATIONSHIP TO PRESENT STUDY

Structural mapping of the Gordon Lake region by Henderson (1941a, 1941b), and Fyson (1975, 1984) outlined a regional 'refold', with a complex deformational history. A portion of the Gordon Lake refold hinge was mapped during this study, with an emphasis on vein-structural relationships.

Fyson (1984, Figure 4) recognised a 'cleavage front' close to the Gordon Lake refold axial trace, and he also indicated that sub-sets of the 'regional', north-west trending S3 cleavage post-date the refold. However, our study shows that S3 forms a divergent cleavage fan which is related to the

refolding. Also S3 is crenulated in the centre of the refold, due to late asymmetrical tightening and hinge migration.

Henderson (1985, p121) noted a regional correlation between turbidite hosted gold-quartz vein occurrences and refold structures (Figure 1), but did not provide an explanation. Our mapping of vein type and distribution indicates a concentration of structurally late quartz veins and breccias along part of the axial trace of the Gordon Lake refold. This suggests an association between refolding and late quartz vein development. Therefore, our study aims to develop predictive structural mapping and prospecting techniques for the location of quartz breccia-vein systems. These systems provide more favorable exploration targets (with their larger vein tonnage potential) as compared to the smaller single vein systems.

A possible regional correlation is also noted between metamorphic grade and the distribution of gold-quartz vein occurrences. Most occurrences lie in the greenschist grade terrane and along the amphibolite-greenschist transition. This possibly suggests an overall metamorphic control on vein forming fluids.

3. GORDON LAKE STRUCTURAL GEOLOGY

Nomenclature for structural elements is based on that of Fyson (1982,1984). Within the map area we recognize three deformational events: D1, D3 and D4. Fyson's D2 was not found at Gordon Lake, but is seen in other regions as remnant, aligned, quartz inclusions in biotite porphyoblasts (S2) and minor F2 folds (Fyson, 1980).

Four structural domains: A, B, C and D are delineated across the refold from S3 cleavage and S4d[1] crenulation cleavage relationships (Figure 2). This division facilitates the structural analysis of the map area, and helps in the interpretation of the refolding mechanism.

3.1. Early F1 Isoclinal Folds

Steeply plunging, curvilinear, isoclinal F1 folds are recognised by stratigraphic facing and fold noses. The Kidney Pond F1 fold has an E-W trending anticlinal axial trace, asymmetric fold limbs, a disrupted fold nose and, 20 m to the south, a corresponding synclinal axial trace. This geometry possibly suggests a fault-propagation fold, as described in thrust belts (Williams et al., 1983). If this interpretation is correct, early structures and bedding-parallel quartz veins (the first veins to form, see section 4) may have developed, by thrusting processes in an accretionary wedge or a thin skinned fold and thrust belt environment. These structures and veins were subsequently overturned during D3. S1 cleavage was not recognized, either it was not formed or was overprinted by D3.

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[1] The subscript 'd' denotes a discrete type of crenulation cleavage morphology, (Gray, 1978).

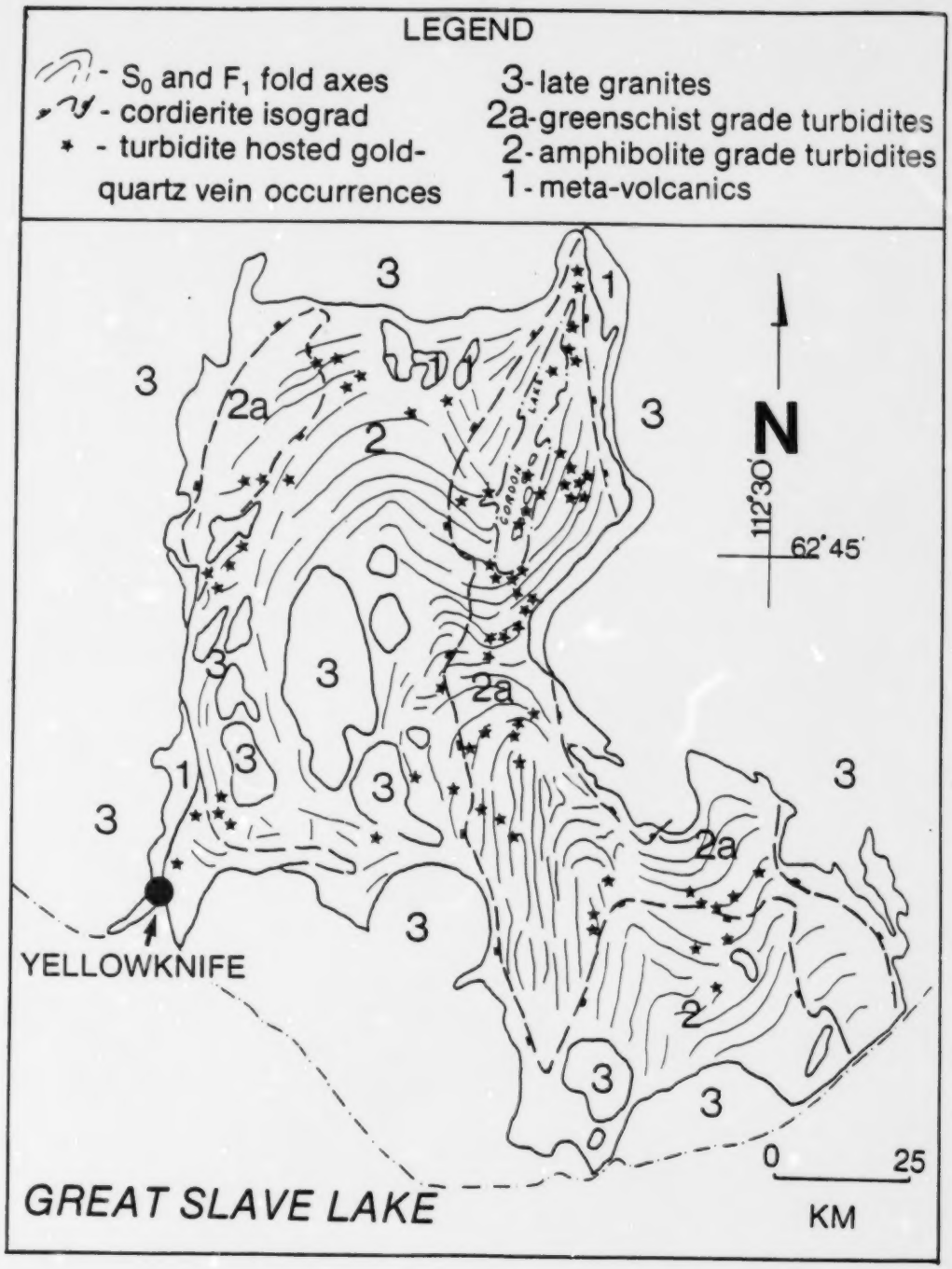


Figure 1. Refold, gold vein occurrences and metamorphic grade relationships within the Yellowknife Basin, compiled from Padgham (1986, Figure 4) and Fyson (1984, Figure 2).

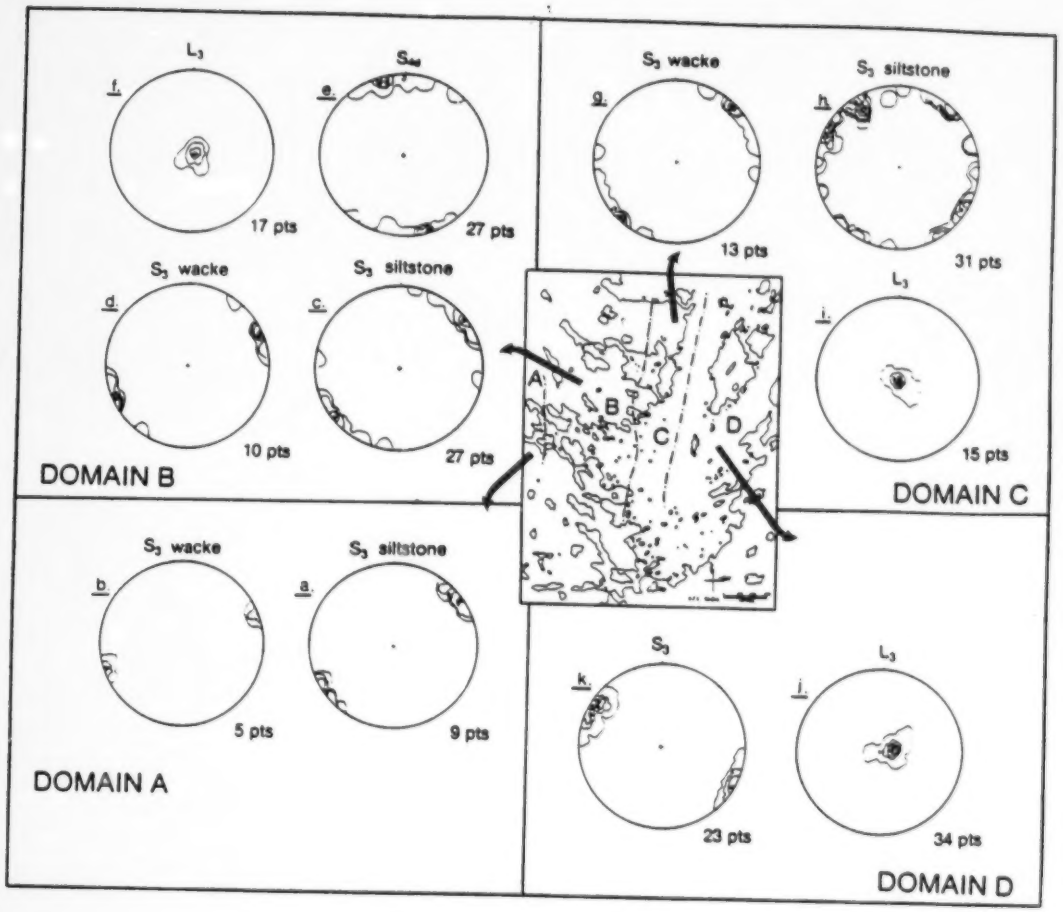


Figure 2. Structural Data of the Gordon lake refold. Lower hemisphere, equal area projection. Domain A; a) S3-siltstone contoured at 11, 19, 35 and 51%/unit area, b) S3-wacke contoured at 20, 48 and 90%/unit area. Domain B; c) S3-siltstone contoured at 4, 14, 44 and 54%/unit area, d) S3-wacke contoured at 10, 30, 40, 50 and 60%/unit area, e) S4d contoured at 4, 24, 34 and 44%/unit area, f) L3 contoured at 6, 26, 56 and 76%/unit area. Domain C; g) S3-wacke contoured at 12, 23 and 38%/unit area, h) S3-siltstone contoured at 3, 6, 9, 12 and 15%/unit area, i) L3 contoured at 7, 34 and 51%/unit area. Domain D; j) L3 contoured at 3, 33, 53, 63, and 73%/unit area, k) S3 contoured at 4, 14, 24 and 34%/unit area.

3.2 D3 Deformation

D3 is represented by the syn-metamorphic, regional S3 cleavage, and F3 folds (1-100m scale). The variation of S3 refraction sense around the refold indicates that S3 was developed by flexural shear, during formation of the refold (Figure 3). Regionally and locally S3 has a steep stretch lineation, L3 (Figs. 2f, 2i and 2j), which is probably related to the subsidence of sedimentary synforms during diapiric emplacement of granites (Dixon et al, 1983), at peak metamorphic conditions (Kaminsni et al., 1979). Metre scale F3 folds have axial traces parallel to S3, whereas 100m scale folds, such as at Lynx Inlet (Map 1), have a similar variation in S3 refraction sense as the large scale refold.

3.4. D4 Deformation

D4 produced a discrete crenulation cleavage, S4d, in the central part of the refold along the axial trace (Domain B). Here, the S3 cleavage lies in the compressional field of a late dextral bedding-parallel shear, resulting in the 70-80° trending, discrete crenulation cleavage, S4d, (Figures 2e and 3). Because only finer grained siltstones are crenulated, a resultant herringbone cleavage pattern is seen. The S4d crenulation cleavage disappears gradually westwards from the axial trace of the refold and is absent in Domain A. However, eastward from the refold axial trace, where S3 is in the extensional field of dextral bedding-parallel shear, quartz veins are boudinaged parallel to S3 and possible extensional crenulations (S4e) develop, (as in Dennis et al. 1987 and Platt et al. 1980)

4. QUARTZ VEIN MORPHOLOGY, DISTRIBUTION AND FORMATION MECHANISMS

Quartz veins are classified on the basis of morphology, interpreted structural timing, and lithological association. Some vein types are restricted to particular areas within the refold (Figure 4). The following morphological types are recognized:

Deformational Phase	Morphological Remarks Type
D1?	Type 1 - Bedding parallel veins (Pre/SynF1?)
D3	Type 2 - Syn-D3, wacke hosted, echelon and reticulate veins.
D3	Type 3 - Syn-D3, siltstone hosted, S3 parallel veins.
D3	Type 4 - Stretched Syn-D3 veins.
D3	Type 5 - Sub-horizontal veins.
D4	Type 6 - Syn-D4, S4d parallel veins.
D4	Type 7 - Quartz breccias (Most important, economical type for Au in the Gordon Lake region).

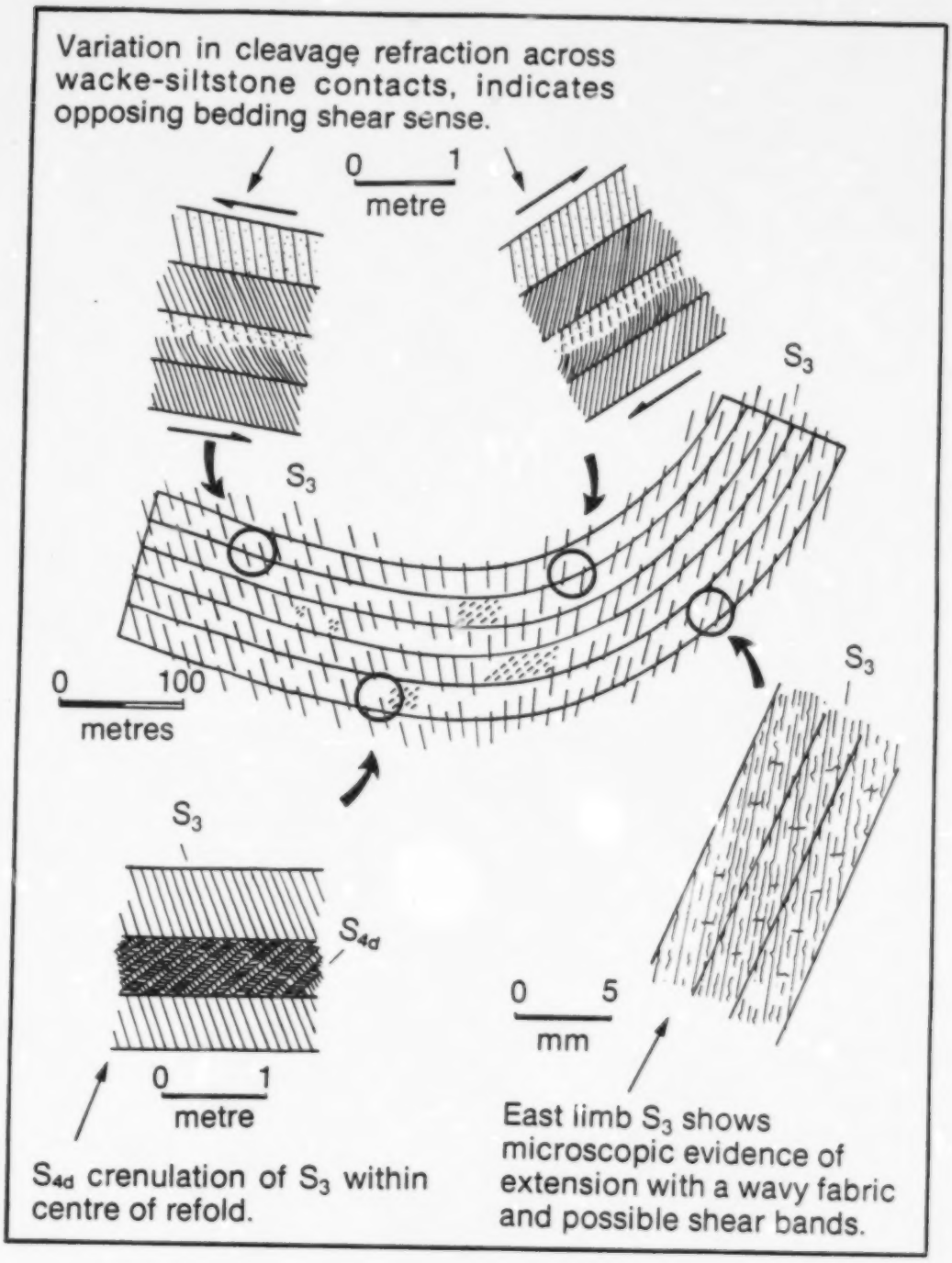


Figure 3. Simplified cleavage-refold relationships at Gordon Lake.

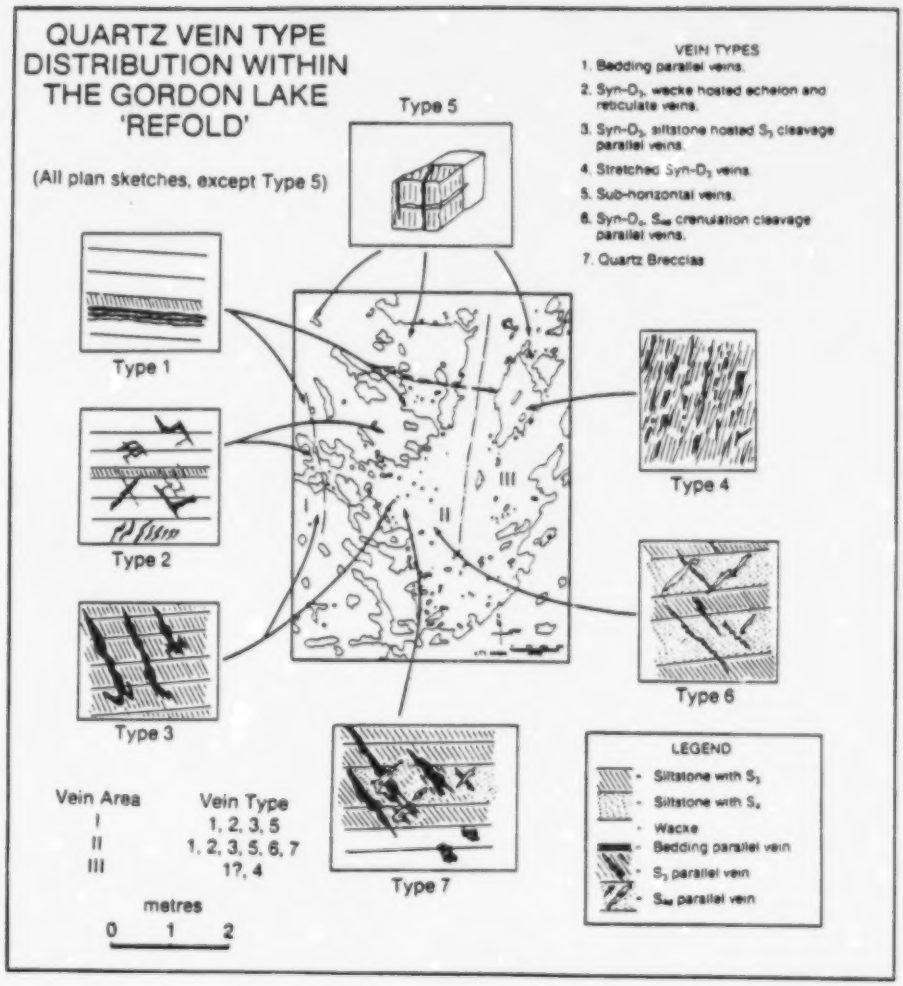


Fig. 4. Distribution of vein types around the Gordon Lake Refold.

Type 1 - Bedding parallel veins.

Bedding parallel veins lie preferentially along bedding contacts and exhibit wallrock selvages, the result of crack-seal formation mechanisms (Figure 5). All are folded and deformed by D3, locally by D4, and in some cases folded around F1 fold hinges. On the refold's east limb these veins are difficult to distinguish from others due to bedding and cleavage parallel boudinage. They consist of 95% recrystallized quartz, with traces of chlorite and opaques.

Type 2 - Syn-D3, wacke hosted, echelon and reticulate veins.

These commonly form echelon arrays perpendicular to the S3 cleavage and also have offshoots parallel S3 (Figure 6), sometimes resulting in a reticulate vein network. They consist of 80-90% recrystallized quartz with 10-20% chlorite, feldspar and opaques. It is suggested that quartz filled extensional and Riedel shear fractures formed preferentially in wackes during D3 bedding-parallel shear, resulting in a varied array of vein orientations (Roberts, 1987, Figure 5). These veins were subsequently deformed as D3 progressed; being rotated, elongated or folded depending on their initial orientation to the S3 direction.

Type 3 - Syn-D3, siltstone hosted S3 parallel veins.

Syn-D3 siltstone hosted veins are recognised by 1) parallelism to S3, 2) larger size than type 2, 3) wallrock fragmentation along S3 (characterized by elongate fragments), and 4) feldspar rich mineralogy. Folded vein arms and tips indicate the synchronous nature of veining relative to S3 development (Figure 7). These veins have a more varied mineralogy with 50-80% undulatory quartz (suggesting that they are microstructurally younger than type 2), 10-30% feldspar, 5-10% chlorite and biotite, plus minor sulphides. The hydraulic fracturing conditions required for vein formation in a foliated rock do not differ greatly from that of an isotropic rock (Kerrich and Fyfe, Figure 12-40, 1987), except that vein direction is in part controlled by the anisotropy orientation, (which in this case is S3).

Type 4 - Stretched Syn-D3 veins.

Type 4 veins are restricted to the eastern limb of the refold, and are recognised by their prominent boudinaged character (Figure 8). These veins lie along S3, but because cleavage strike in this region is within 10-20° of the refold limb, they also lie sub-parallel to bedding. These veins contain 60-80% quartz (which is recrystallized in boudin necks), 10-20% carbonate material, and minor mica, chlorite and opaques. Type 4 veins are the result of Types 1, 2, and 3 veins which have undergone extension parallel S3.

Type 5 - Sub-horizontal veins.

Sub-horizontal veins are visible on vertical outcrop surfaces and cross-cut the steep D3 stretch lineation (Figure 9). Mineralogically these veins are similar to the Syn-D3, Type 3 veins. In the west they are undeformed

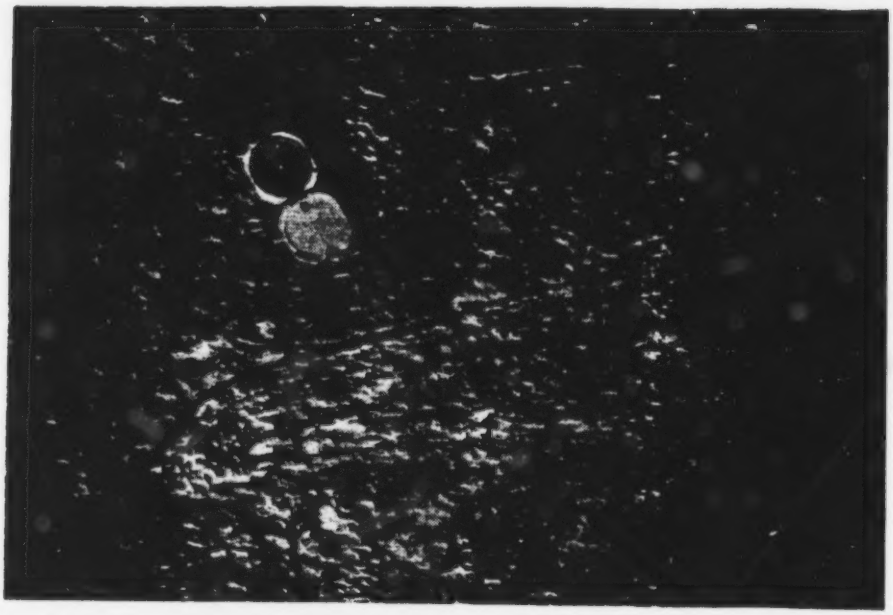


Figure 5. Type 1 - Bedding parallel vein, displaying crack-seal characteristics is folded around an F1 fold nose. Compass points along the transecting, 'regional' S3 cleavage.

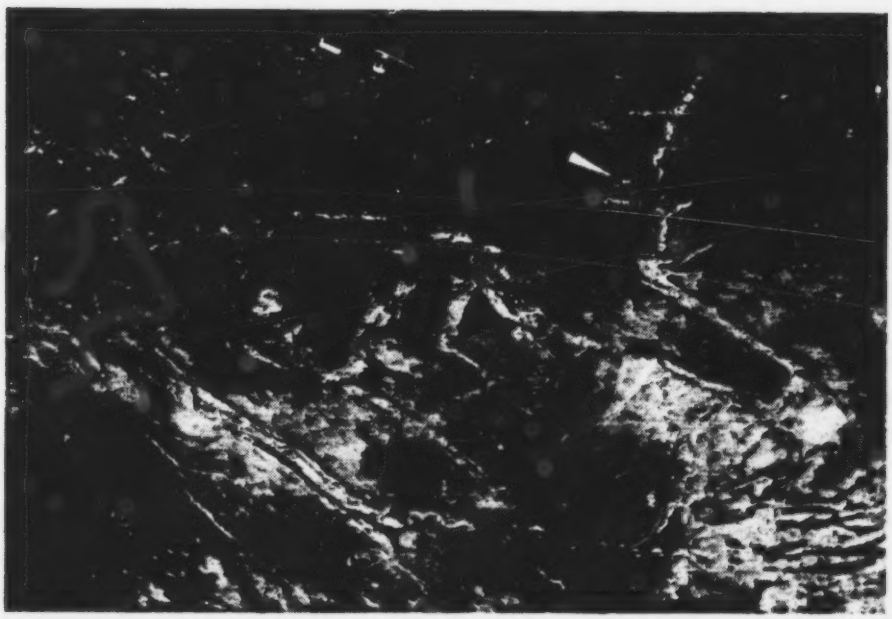


Figure 6. Type 2 - Syn-D3, echelon veins with offshoots parallel to the S3 cleavage, forming a reticulate network structure.

Figure 7. Type 3 - Syn-D3 veins in siltstones forming parallel S3, and cross-cut earlier formed F3 folds. Folding of vein tips indicates a syn-deformational relationship.

Figure 8. Type 4 - East limb Syn-D3 veins showing evidence of intense horizontal stretching and vein boudinage.

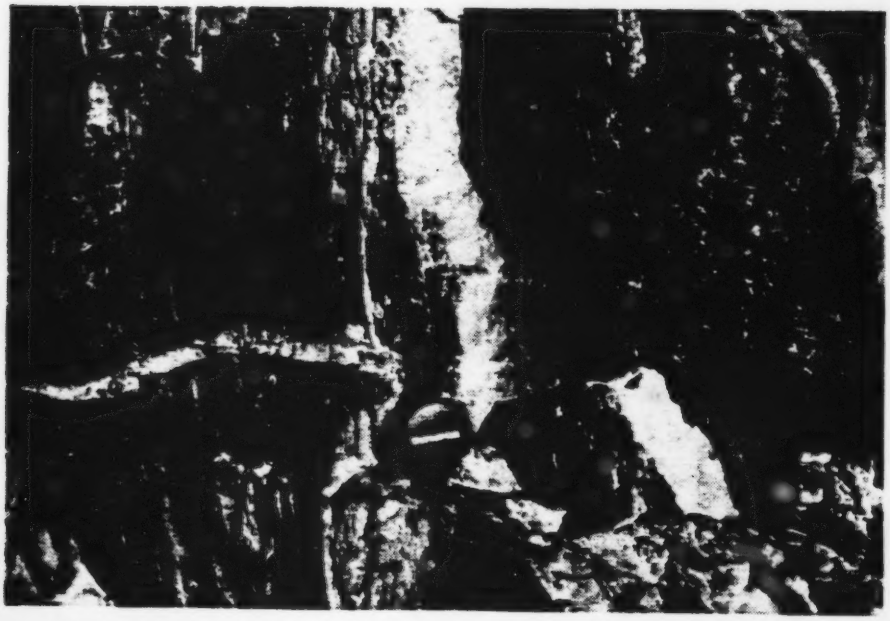


Figure 9. Type 5 - Horizontal vein cross-cutting vertical stretch and abutting/cross-cutting Syn-D3, Type 3 veins.

but appear more folded eastwards across the refold. These veins probably formed late in D3 by extensional fracturing perpendicular to the vertical stretch.

Type 6 - Syn-D4, S4d parallel veins.

Syn-D4 veins are concentrated along part of the refold's axial trace and are characterized by: 1) parallelism to the S4d crenulation cleavage, 2) cross-cutting Syn-D3 and bedding parallel veins (Figure 10), 3) D4 folded vein tips and arms, and 4) feldspar rich vein rims. These veins formed by hydraulic fracturing in a similar manner to the Type 3 veins.

Type 7 - Quartz breccia veins.

Quartz breccia veins are comprised of wallrock fragments, both framework and matrix supported, in a quartz-feldspar rich mass with minor mica, carbonate, sulphides and gold (Figure 11). Only minor fragment rounding and rotation is present. Fragments contain both S3 and S4 cleavage traces and are commonly fractured along these surfaces. Breccia zones appear sub-parallel to bedding with carbonaceous shears along the breccia-host rock contacts. Individual Type 3, 5 and 6 veins are recognizable. Breccias are hosted in both siltstones and wackes, but fragmentation (hence breccia zone size) is enhanced within siltstone lithologies (particularly carbonaceous); as siltstones are more susceptible to the development of anisotropies than wackes. (This characteristic is observed when comparing the size and continuity of the larger, siltstone hosted, Kidney Pond breccia to the poddy and irregular wacke hosted breccias, south of the Lynx Inlet.)

Fluid overpressuring during D4 results in controlled fragmentation along both S3 and S4 (Figure 12), forming both Type 6, Syn-D4 veins and brecciation zones. Complex vein stockworks are formed where earlier Type 2, 3 and 5 veins are overprinted by D4 brecciation.

Economic gold mineralization, based on present and past mining activities at the south end of Gordon Lake, appears related to zones of intense Type 7, quartz-brecciation (i.e. the Kidney Pond zone,) and Type 4, stretched Syn-D3 veins, (i.e.'31' Vein and Camlaren(?), Map 1). Therefore the economic gold mineralization appears preferentially associated with structurally late veining events, and is focussed towards the refold's centre along the axial trace.

5. SUMMARY OF THE BRECCIA-VEIN FLUID FOCUSSING MODEL

F1 isoclinal folds, now with vertical plunges, are formed during deformation and thrusting of a turbidite pile or accretionary wedge. Dewatering of the sedimentary pile and crack-seal mechanisms produce veins along weakness between bedding interfaces (Type 1). The isoclinal folds were overturned and refolded during D3. D3 resulted in : 1) a syn-metamorphic S3 regional cleavage with a divergent cleavage fan (Figure 13), 2) a vertical plunging N-S trending refold, 3) a steep stretch lineation. During D3 metamorphically derived veins formed distinct types in different host

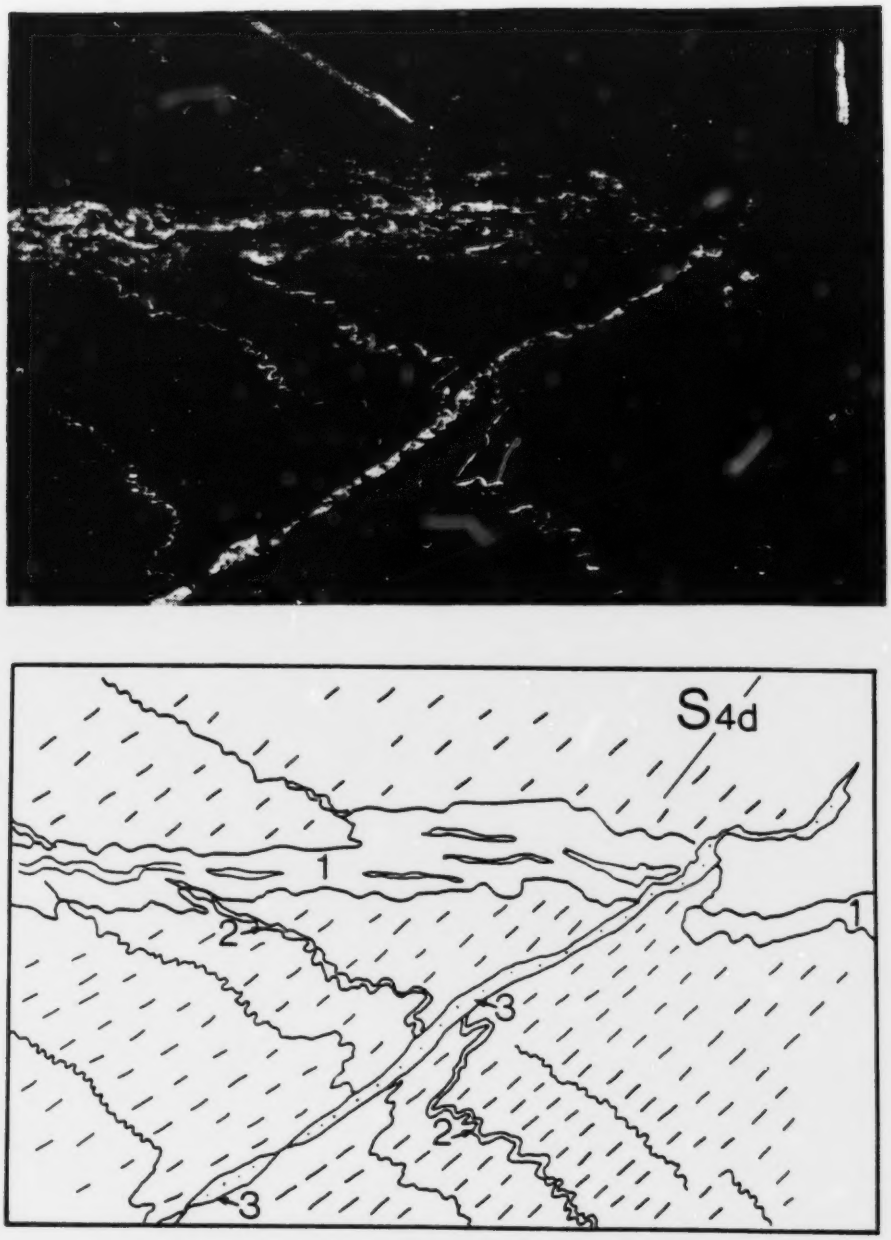


Figure 10. Type 6 - Syn-D4 vein parallel the S4d crenulation cleavage, cross-cutting Syn-D3 (Type 3) and bedding parallel (Type 1) veins. Pen along S3 orientation. 1) D3 and D4 deformed bedding parallel vein with rock selvages. 2) F4 folded Syn-D3 vein abutting/cross-cutting bedding parallel vein. 3) Syn-D4 vein along S4d crenulation cleavage cutting bedding parallel and Syn-D3 vein

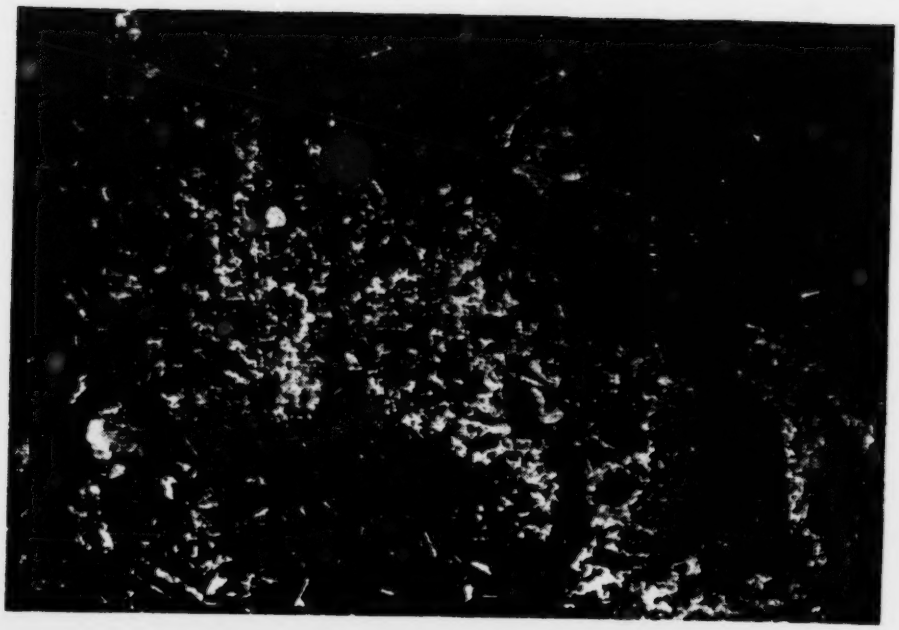
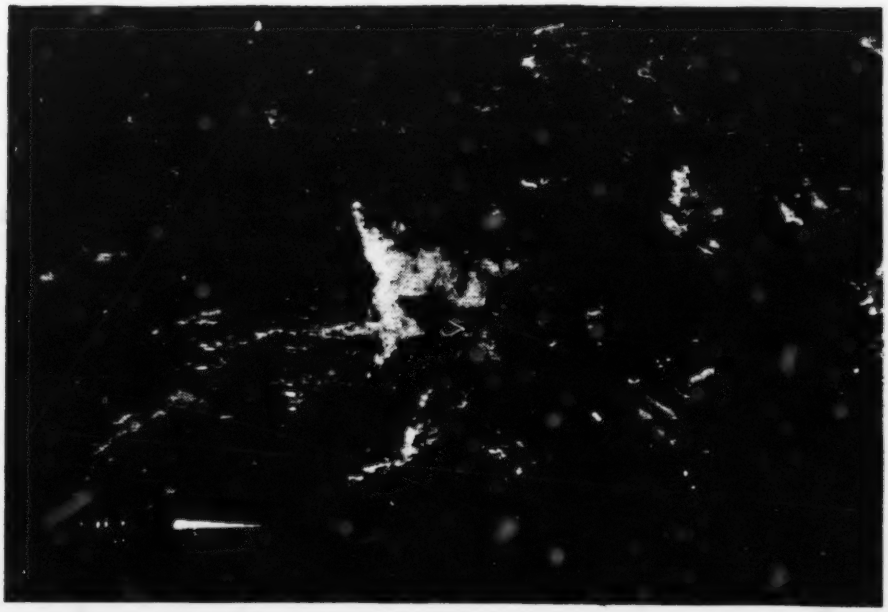


Figure 11. Area of brecciation adjacent to the Kidney Pond mineralized zone.



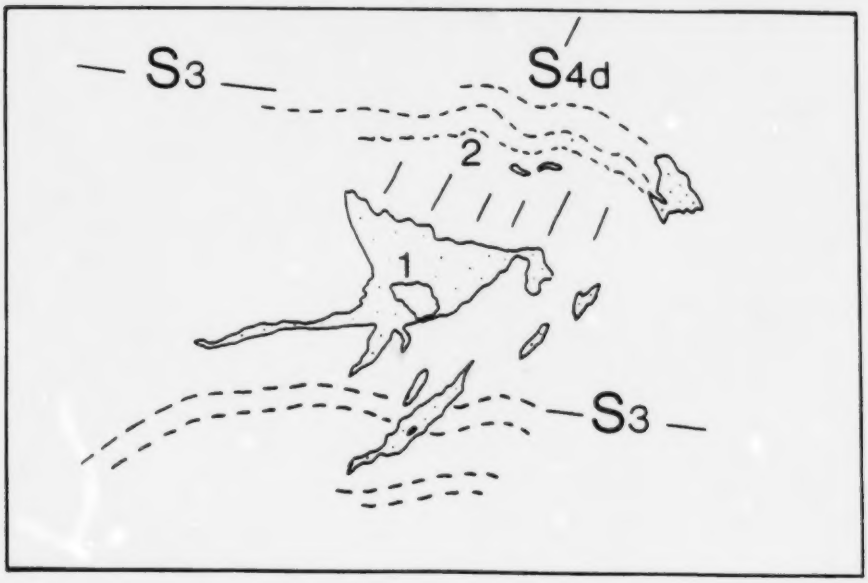


Figure 12. Type 7 - D4 quartz-brecciation process, fracturing and vein infilling along S3 and S4 anisotropies. 1) Syn-D4 brecciation vein and wallrock fragmentation. 2) F4 crenulation folding of S3 cleavage.

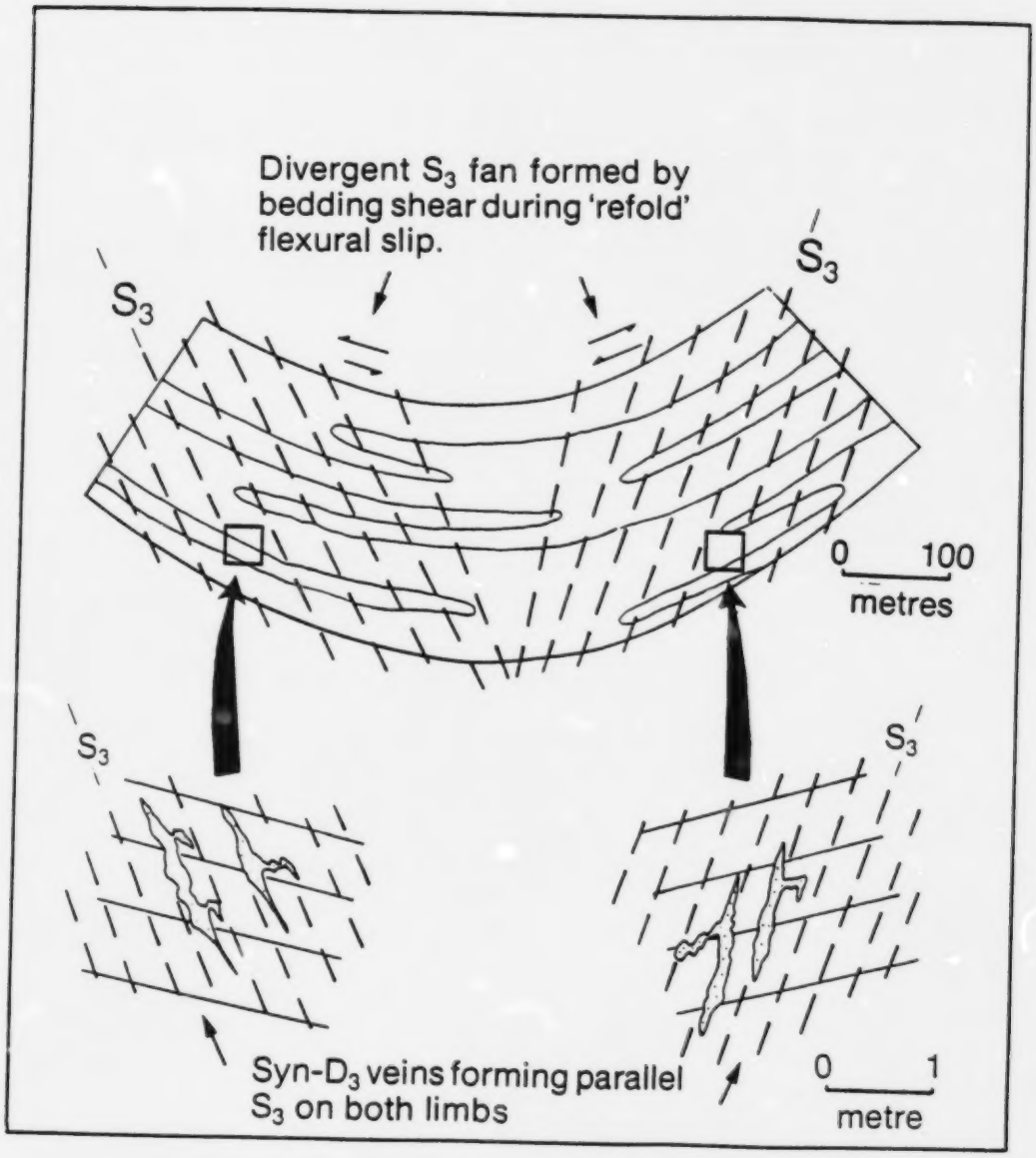


Figure 13. Refolding Model: Stage I, D3 Deformation and Syn-D3 vein formation.

lithologies. In wackes, veins formed in extensional and shear fracture arrays during bedding-parallel shear (Type 2), whereas in siltstones veins formed parallel to the S3 anisotropy (Type 3). Sub-horizontal veins (Type 5) formed in fractures perpendicular to the D3 vertical stretch.

As deformation progressed asymmetrical tightening and hinge migration of the refold's east limb produced a bedding parallel, sub-horizontal dextral shear (Figure 14). (Tightening was probably assisted by a competency contrast between the wacke-dominated west limb and the siltstone-dominated east limb.) This bedding parallel shear resulted in discrete crenulation of the S3 cleavage (forming S4d) in the zone of hinge migration, and extension parallel to S3 (plus vein boudinage) on the east limb. D4 overpressuring of late metamorphic fluids formed veins along S4d (Type 6) and brecciation zones (Type 7); the latter was assisted by the existance of S3 and S4d anistropies. Hence, late vein formation was focussed and concentrated into regions of crenulation, formed by hinge migration, which lie in the centre of the refold along the axial trace.

6. RECOMMENDATIONS FOR FUTURE WORK

Field work is required to further document and test the model of refolding, crenulation and late quartz breccia-vein focussing at Gordon lake. Work should include: 1) Mapping of the refold axial trace to define closer the quartz breccia distribution. 2) An examination of Giant Bay's core from the Kidney Pond zone and other quartz breccia zones to determine the alteration, mineralogy, structure and 3'D'shape of 'typical'quartz breccia bodies. 3) Detailed traverses east and west from Gordon Lake to establish better the regional structural, lithological, and metamorphic setting of the refold.

The source and characteristics of the late vein mineralizing fluids are poorly constrained. Are they locally derived, related to cleavage formation, or from deeper (metamorphic/ igneous) sources? (Previous isotope and fluid inclusion work by English (1980) and Swatton (1987) suggest that metamorphic devolitilization was an important vein fluid forming process.) How was the gold precipitated, was it a function of decompression during hydraulic fracturing, and is it also related to the carbon content of Burwash siltstones? How is the gold distributed (mineralogically) within the veins? Geochemical, stable isotope and fluid inclusion work, using well selected samples, will assist in determining and constraining fluid source, vein formation temperatures, and fluid composition. Dating by $^{40}Ar/^{39}Ar$ techniques of micas from the quartz breccia, the metamorphic event and the late plutonic phase might assist in determining the timing of regional uplift, refolding, and the late mineralizing event.

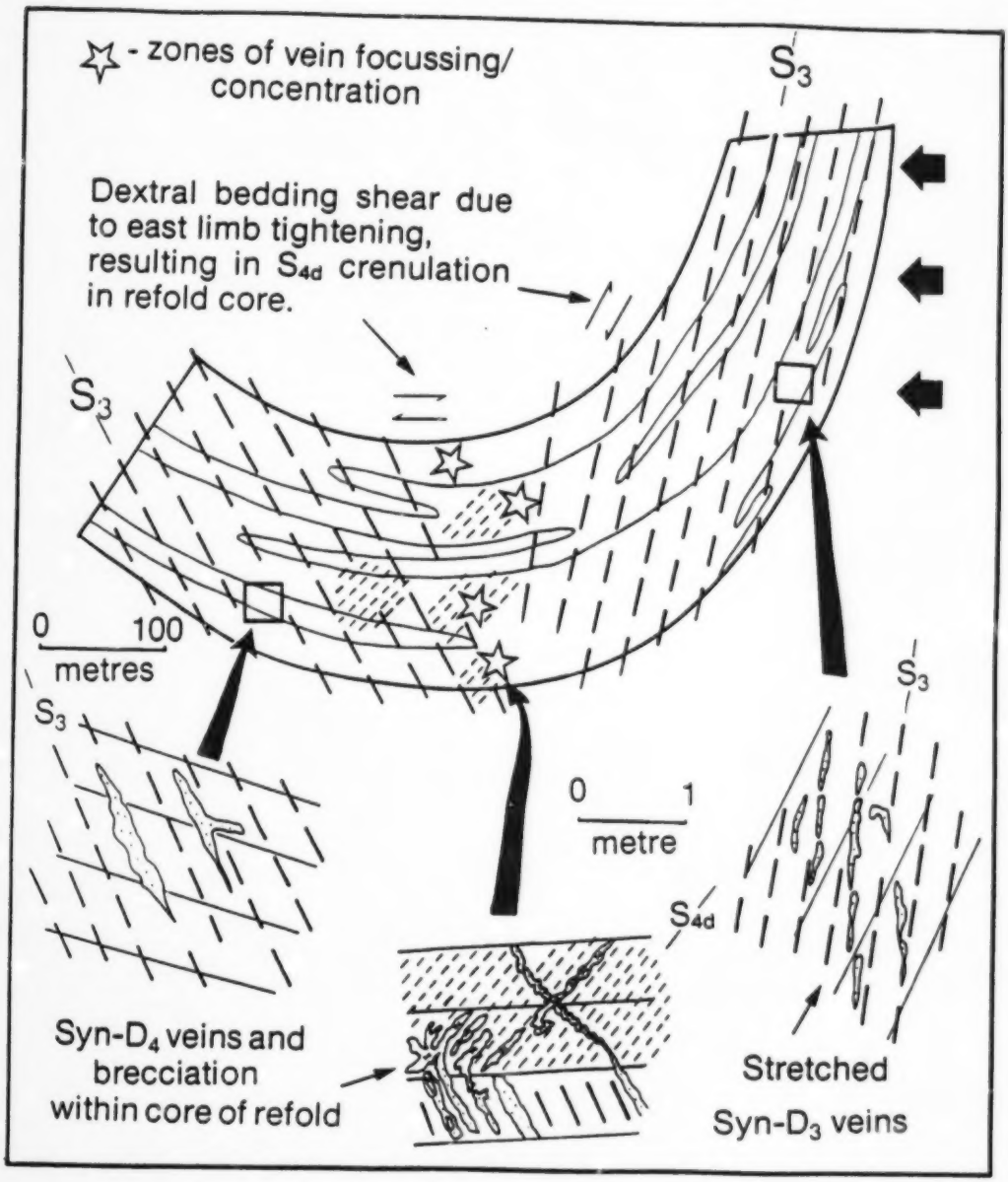


Figure 14. Refolding Model: Stage II, Progressive D4 asymmetrical tightening of refold's east limb and hinge migration.

7. PRACTICAL EXPLORATION HINTS FOR THE DISCOVERY OF ADDITIONAL QUARTZ-BRECCIA DEPOSITS

How is this focussing model and study useful to the exploration industry?

At Knight Bay the quartz-breccias appear related to crenulation zones along the axial trace of the Gordon Lake refold. Therefore other refolds and crenulation zones are potential targets for this type of mineralization. Crenulation zones provide regionally predictive and mappable targets that can define regions of interest or desired claim blocks. Also regional, lithological contrasts within refolds are possible targets for localizing crenulation zones.

Of the siltstone lithologies, black, carbonaceous units appear the most favourable hosts for quartz breccias with larger tonnage and continuity as compared to wacke hosted breccias, based on anisotropy development and fracturing characteristics. However, the siltstone hosted breccia bodies, such as the Kidney Pond zone, do appear hidden under swamps or low lying ground (due to their relative ease of erosion?).

8. CONCLUSIONS

1. S3 cleavage development is a result of flexural shear during the formation of the Gordon Lake refold. D4 asymmetrical tightening of the refold's east limb and hinge migration results in the formation of crenulation cleavage (S4d) zones concentrated in the centre of the refold along the axial trace.

2. Brecciation is concentrated in the refold's axial trace, the zone of postulated hinge migration, and is the result of D4 fluid overpressuring and fragmentation along S3 and S4d anisotropies.

3. Most economic gold mineralization appears associated with the late quartz veins and brecciation.

4. It is suggested that refolding and crenulation are the mechanisms for controlling fluid focussing and the formation of auriferous quartz-brecciation zones.

5. From this 'vein concentration' model it should be possible to identify other areas favorable for quartz-brecciation within the Yellowknife Basin, and investigate them by mapping refold and crenulation structures.

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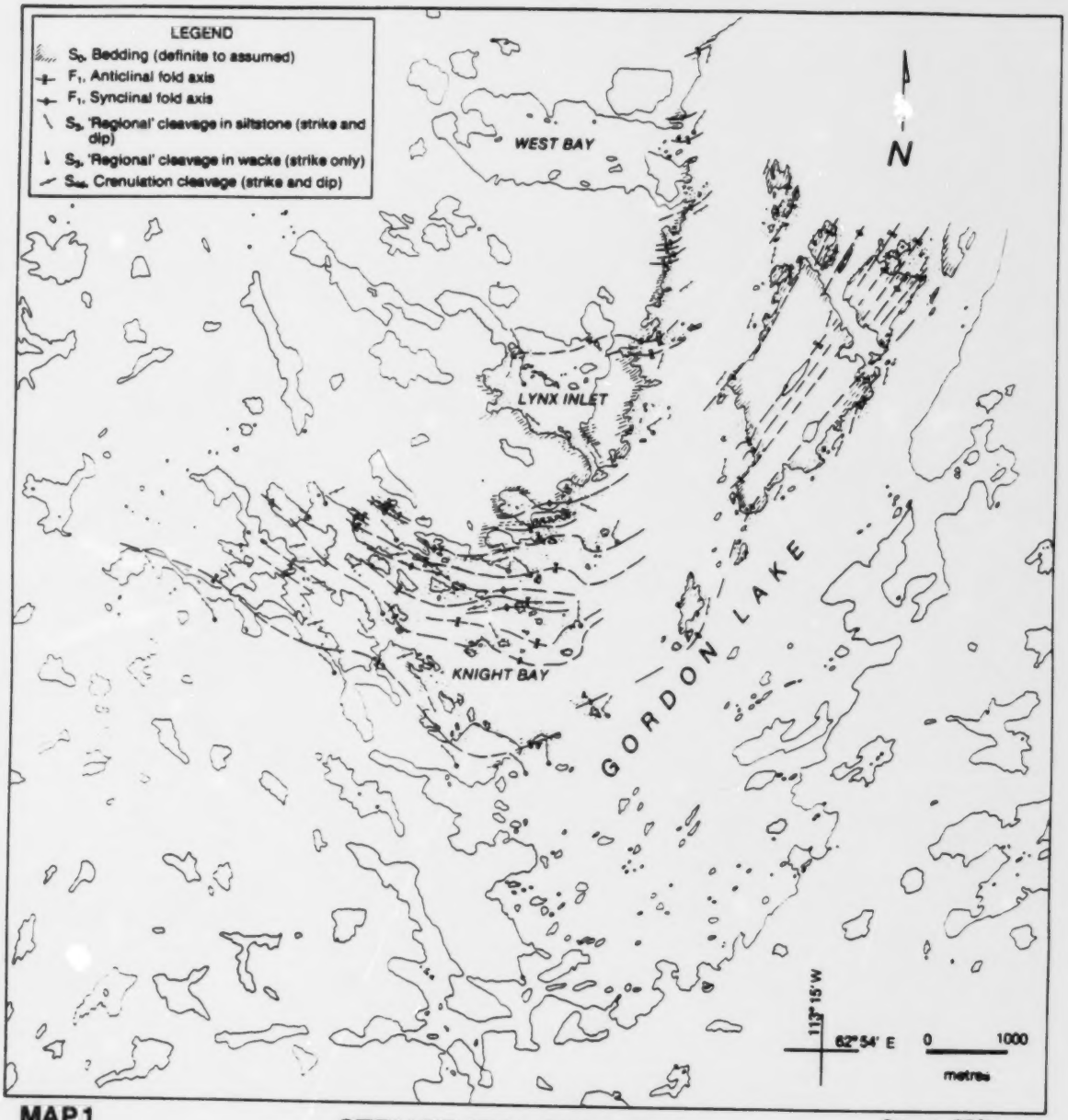

MAP 1

STRUCTURAL GEOLOGY OF THE GORDON LAKE 'REFOLD' HINGE

Drawn by T.R.Stokes

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